Assessment of Pb-Free Norris-Landzberg Model to JG-PP Test Data

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Introduction

Why the comparison

- To determine whether the lead-free Norris-Landzberg model fits the JCAA/JG-PP test data

How the comparison was done

- Determined acceleration factors (AF) by comparing characteristic life from thermal cycle conditions' test data
- Calculated the predicted AFs from the thermal cycle test conditions using the lead-free Norris-Landzberg model
- Compared the predicted AF to the observed AF for each set of test conditions to see how well they correlate

Norris-Landzberg Equation (Pb-Free)

$$AF = \frac{N_o}{N_t} = \left(\frac{\Delta T_t}{\Delta T_o}\right)^{2.65} \left(\frac{t_t}{t_o}\right)^{0.136} \exp\left\{2185\left(\frac{1}{T_{\max,o}} - \frac{1}{T_{\max,t}}\right)\right\}^{1}$$

AF – acceleration factor

N – thermal fatigue life

ΔT - temperature difference

t – dwell time (min)

T_{max} – maximum cycle temperature (K)

o, t – operating or test conditions

[1] N. Pan et al, "An Acceleration Model For Sn-Ag-Cu Solder Joint Reliability Under Various Thermal Cycle Conditions". pp. 876-883, SMTAI, September 2005, Chicago, IL

Where the data came from

JGPP Test Data:

- "JCAA/JG-PP No-Lead Solder Project: -20^{o}C to +80^{o}C Thermal Cycle Test" T. Woodrow, The Boeing Company
- "JCAA/JG-PP No-Lead Solder Project: -55^{o}C to +125^{o}C Thermal Cycle Testing Status Report" Dave Hillman, Rockwell Collins
- "JCAA/JG-PP No-Lead Solder Project: Thermal Shock Testing" T. Woodrow, Boeing Phantom Works

HP data:

- "An Acceleration Model For Sn-Ag-Cu Solder Joint Reliability under Various Thermal Cycle Conditions" N. Pan, et al., Hewlett-Packard

Characteristic Life / Acceleration Factors (AFs)

Part		ΔT (°C)	t_d (min)	η	T_{max} (K)
TSOP	$o_{1,2,3,4}$	100	30	4141.06	353.15
	$t_{1,5,7}$	180	30	1061.76	398.15
	t_2 , $o_{5,6,7}$	180	15	1168.48	398.15
	$t_{3,6}$	180	15	1109.77	398.15
	$t_{4,7}$	180	30	1157.20	398.15

Comparison	N.L	Test	% Diff
1	9.6	3.9	245
2	8.7	3.5	245
3	8.7	3.7	233
4	9.6	3.6	267
5	1.1	1.1	100
6	1.0	1.1	95
7	1.1	1.1	100

Part		ΔT (°C)	t_d (min)	η	T_{max} (K)
CLCC	$o_{1,2}$	100	30	2360.22	353.15
	$t_{1,}$ o_3	180	30	508.67	398.15
	$t_{2,3}$	180	15	680.96	398.15

Comparison	N.L	Test	% Diff
1	9.5537	4.6400	205.90
2	8.6942	3.4660	250.84
3	0.9100	0.7470	121.83

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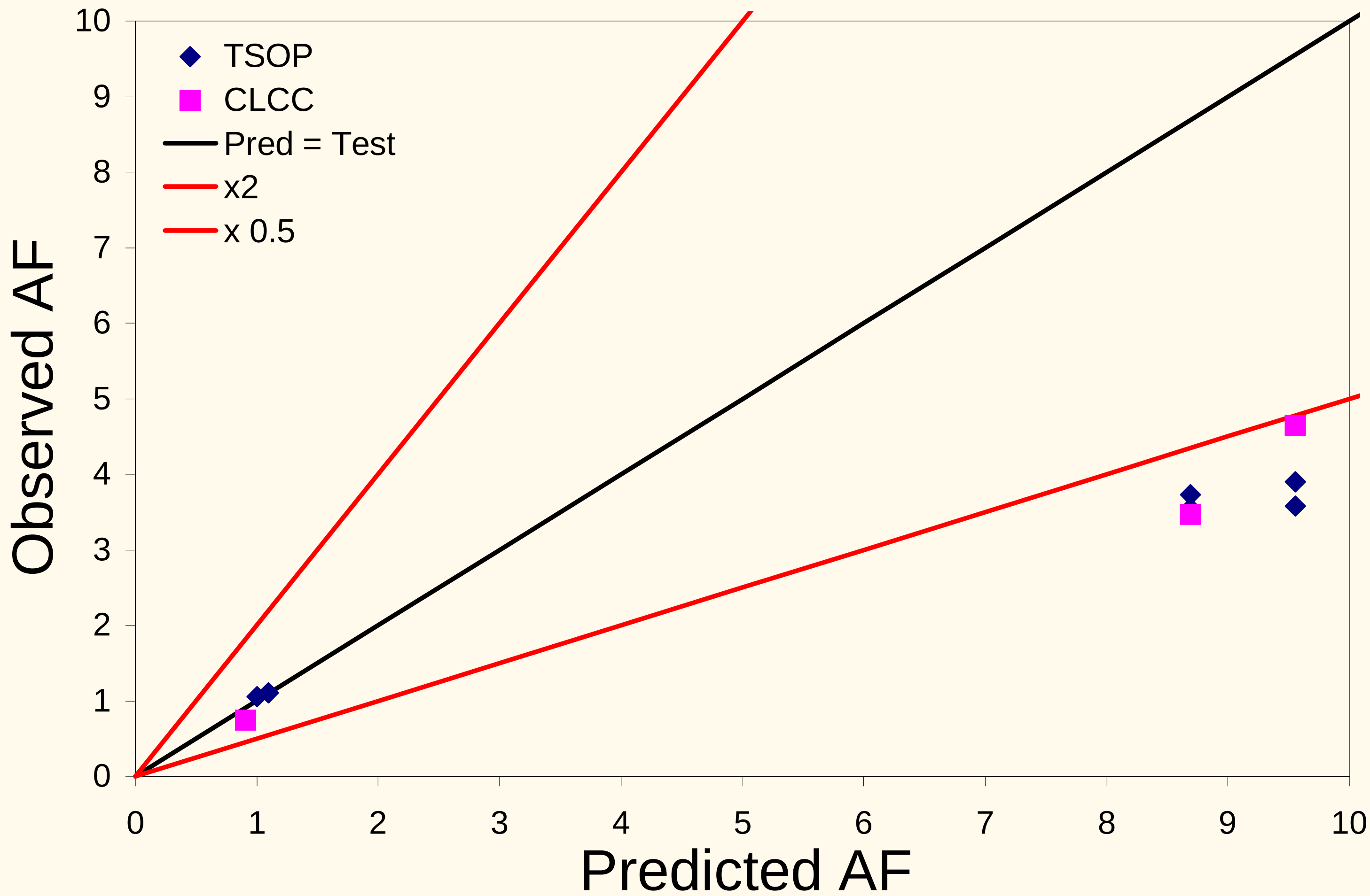
Predicted vs. Observed AF



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Observations

- The Norris-Landzberg seems to over predict AFs for the JG-PP data
- Specifically, JG-PP test vehicles are either
  - Failing sooner than expected under benign conditions, or
  - Lasting longer under severe conditions
- Why?
  - Test results may be invalid
  - NL model may be inaccurate outside certain parameters

Validity of Test Data

- Compared to data obtained by Motorola[2] and HP, using similar components, the JG-PP TSOP has a longer characteristic life
  - Thermal Shock
    - JG-PP (-55 to 125 C, 15 min dwell): η – 1168 cycles
    - Motorola (-55 to 125 C, 15 min dwell): η – 613 cycles
  - Thermal Cycling
    - JG-PP (-20 to 80 C, 30 min dwell): η – 4141 cycles
    - Motorola (0 to 100 C, 15 min dwell): η – 2564 cycles
    - HP (0 to 100C, 10 min dwell): η – 1843 cycles
      η – 3071 cycles

However, ratios of time to failure are relatively constant (~4:1)

[2] G. Swan et al, "Development of Lead-Free peripheral Leaded and PBGA Components to Meet MSL3 at 260C Peak Reflow Profile". LF2-6 pp.1-7. IPEX 2001

Validity of Model

- Constants based on test data from area array (BGA, CSP) and leaded (TSOP) devices
  - Except for one condition, test environments limited between 0 to 100C
  - Wide range in time to failures (150 to 10000 cycles)
- Seems to over predict effect of maximum temperature and change in temperature
  - Constants more inline with SnPb NL model may provide a better fit to the test data

Validity of Model (cont.)

SnPb Norris-Landzberg (NL) Model

$$AF = \frac{N_o}{N_t} = \left(\frac{\Delta T_t}{\Delta T_o}\right)^{2.0} \left(\frac{t_t}{t_o}\right)^{0.136} \exp\left\{1414\left(\frac{1}{T_{\max,o}} - \frac{1}{T_{\max,t}}\right)\right\}$$

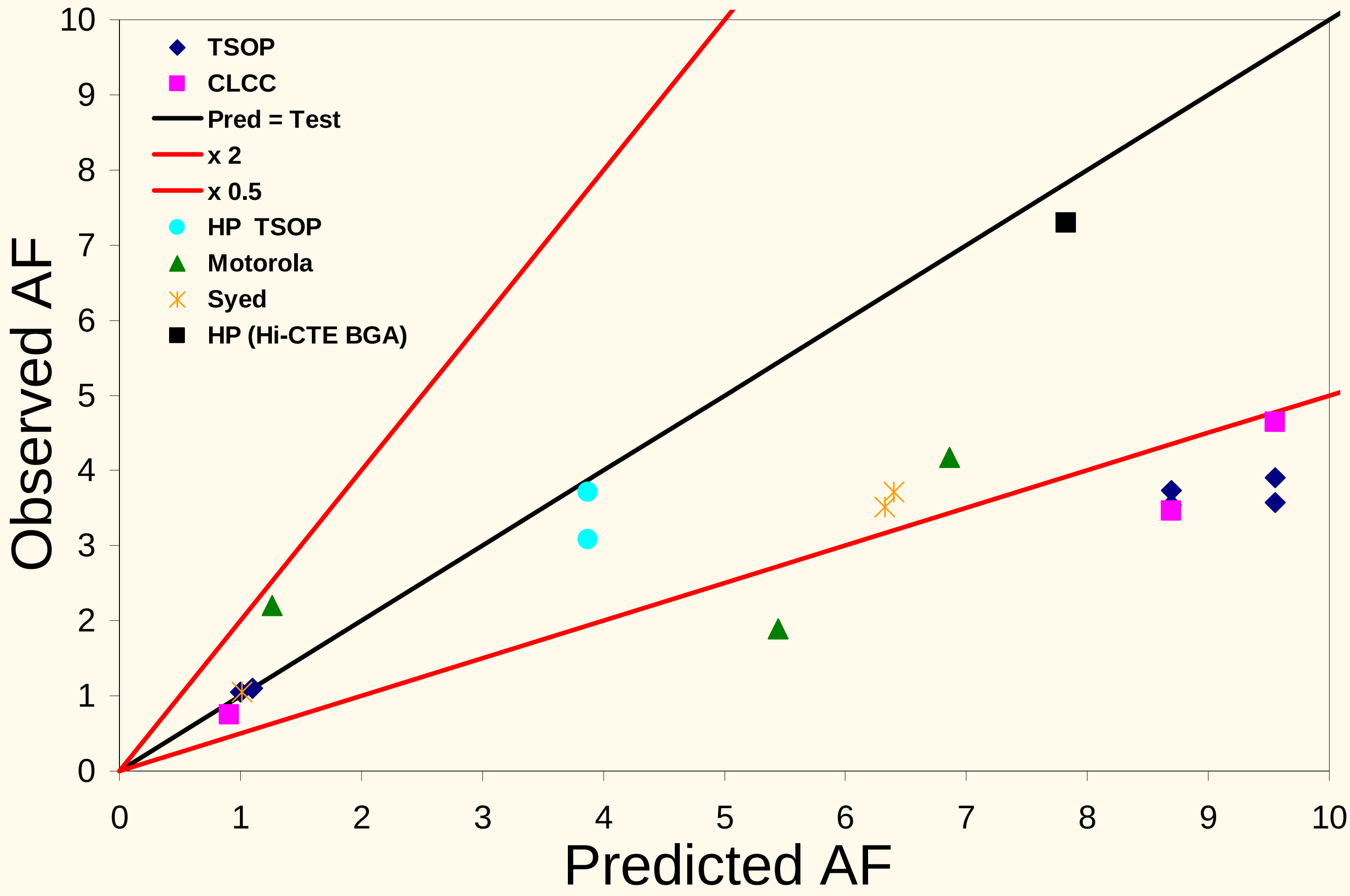
• replaced coefficients with original from SnPb model
2.65 → 2.0 and 2185 → 1414

- Compared to Pb-free NL model, the constants from the SnPb NL
  - Provide better predictions
    - All data points, from multiple studies, are within a 2x range
  - A more conservative

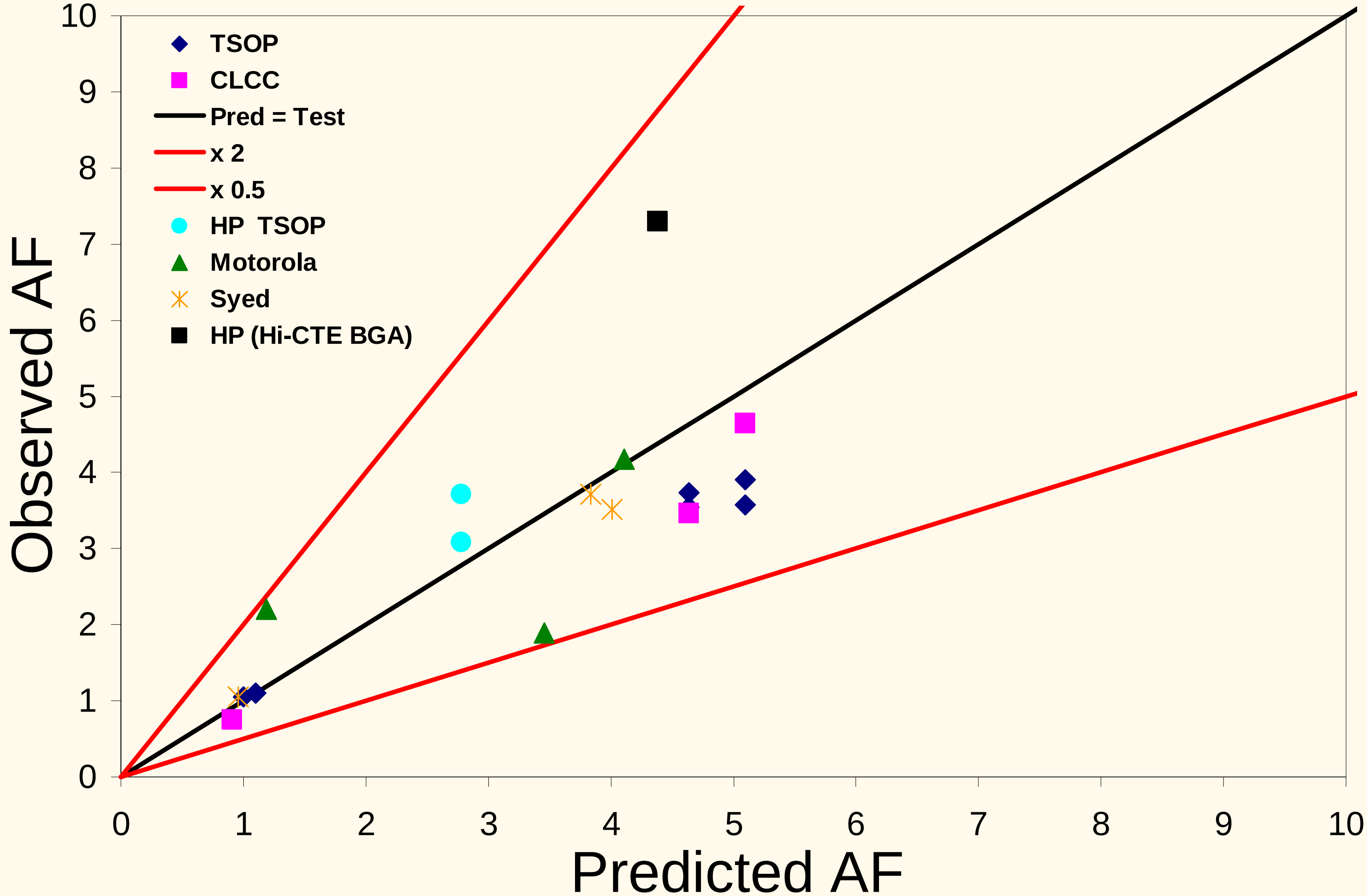
Data from other Experiments

Motorola		ΔT (^oC)	t_d (min)	η	T_{max} (K)		Comparison	N.L	Test	% Diff
	o	100	15	2564	373		1	3.4545	1.8936	182.42
	t1	165	15	1354	398		2	4.1111	4.1759	98.45
	t2	180	15	614	398		3	1.1901	2.2052	53.97
HP		ΔT (^oC)	t_d (min)	η	T_{max} (K)		Comparison	N.L	Test	% Diff
	o	60	10	6849	373		1	2.7778	3.7162	74.75
	t1	100	10	1843	373		Comparison	N.L	Test	% Diff
	o	60	10	9455	373		1	2.7778	3.0788	90.22
	t1	100	10	3071	373					
Syed (flexBGA)		ΔT (^oC)	t_d (min)	η	T_{max} (K)		Comparison	N.L	Test	% Diff
	o	100	5	10370	373		1	4.0112	3.5176	114.03
	t1	165	15	2948	398		2	3.8352	3.7142	103.26
	t2	180	3	2792	398		3	0.9561	1.0559	90.55
HP (HiCTE BGA)		ΔT (^oC)	t_d (min)	η	T_{max} (K)		Comparison	N.L	Test	% Diff
	o	60	10	6206	333		1	4.3798	7.3012	59.99
	t1	100	10	850	373					

Lead free Norris-Landzberg Model



SnPb Norris-Landzberg Model



Conclusion

- The SnPb constants for the Norris-Landsberg model seem to be a better fit to the existing Pb-free data then the revised constants provided in the paper by Pan, et. al.
  - While the paper did a good job in investigating dwell times, a broader range of test data may be necessary before definitive constants can be obtained